DEFENCE R&D DÉFENSE

Buy & Try Testing of MGP DMC 2000S and NRC UDR-13A Dosimeters Final Report of Tasking W28476KR00A (DSSPM)

D.S. Haslip, T. Cousins, D. Estan, T.A. Jones, and B.E. Hoffarth
Defence Research Establishment Ottawa

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL MEMORANDUM
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Space Systems and Technology Section

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ABSTRACT

The MGP DMC 2000S and the NRC UDR-13A electronic dosimeters have been tested by DREO for acquisition project G2199 "Nuclear Detection, Identification and Dosimetry". These tests were carried out with the wide array of radioactive sources available at DREO, with the X-ray facility available at the National Research Council, and with one of the environmental chambers available at the Quality Engineering Test Establishment (QETE).

Both meters are capable devices, suitable for the electronic dosimetry role. However, DND must be aware of the following shortcomings:

(a) Their energy response is not constant. This is not a critical problem since personal dosimetry will be carried out with Thermoluminescent Dosimeters (TLDs).
(b) When placed on certain parts of the reader, the MGP dosimeters will register high levels of radiation in the absence of such a field. This shortcoming must be discussed with MGP.
(c) The MGP dosimeter, due to the small size of the detector, is not suitable for an expanded role including tasks suited to a radiation survey meter.
(d) Neither meter is operable following long-term (2-hour) exposure to temperatures below –20°C. However a dosimeter worn under a coat should be operable without problems.

RÉSUMÉ

Les dosimètres électroniques, MGP DMC 2000S et NRC UDR-13A, ont été testés par CRDO pour le projet G2199 "Service de la Défense pour la Détection, l'Indentification et les Dosimètres Nucléaires". Les essais ont été effectuées avec des sources de rayonnement à CRDO, avec la machine de rayon X au Conseil National de Recherches Canada, et à la Centre d'Essais Techniques de la Qualité (CETQ).

Les deux mètres sont les dispositifs capables, approprié au rôle d'un dosimètre électronique. Cependant, MDN doit se rendre compte des problèmes avec les dosimetres:

(a) Leur réponses d'énergie ne sont pas constants. Cette imperfection n'est pas critique parce qu'on utilise les dosimètres thermoluminescent (TLDs) pour la dosimétrie personnelle.
(b) Quand ils sont placés directement sur certaines parties du lecteur, les dosimètres MGP enregistrent les niveaux très élevés du rayonnement en l'absence d'un champ de rayonnement. On doit parler à MGP sur cette problème.
(c) À cause de son petit détecteur, le dosimètre MGP n'est pas approprié à un rôle augmenté qui inclut des tâches convenues à un mètre d'enquête de rayonnement.
(d) Les deux dosimètres ne sont pas fonctionnels après exposition à long terme (de 2 heures) aux températures au-dessous de -20°C. Cependant, un dosimètre porté sous un manteau devrait être fonctionnel à ces températures.

EXECUTIVE SUMMARY

Document Number: DREO TM 1999-109
Title: Buy&Try Testing of MGP DMC 2000S and NRC UDR-13A Dosimeters (U)
Authors: D. S. Haslip, T. Cousins, D. Estan, T. A. Jones, and B. E. Hoffarth
Defence Research Establishment Ottawa

Background: As part of its continuing mission to provide engineering and technical support to Defence Services Procurement Project G2199, the Radiation Effects Group at DREO has tested the MGP DMC 2000S electronic dosimeter, the MGP LDM 2000 reader, and the NRC UDR-13A dosimeter. The tests included a complete characterisation of their radiation response as a function of dose rate and energy, range and shielding tests of the MGP dosimeter reader, and low- and high-temperature performance studies.

Results: The tests have demonstrated that both the MGP and NRC meters are suitable for the electronic dosimetry role. The two devices clearly have contrasting strengths and weaknesses; the MGP dosimeter is small and lightweight, with a remote transmission capability enabling it to download mission data to a reader, while the NRC dosimeter is built to take on roles outside those of the conventional electronic dosimeter, such as basic gamma radiation reconnaissance or survey.

Neither device is without its shortcomings. Both have energy response curves that are far from flat. Neither is capable of extended operation at temperatures below –20°C. Finally, if the MGP dosimeter is placed on or near certain locations on the reader, it will behave as though exposed to very high levels of radiation.

Significance and Future Plans: These test results will be very valuable to G2199 in refining their requirements. DREO will continue to provide to the project the expertise necessary to ensure that the CF gets the most appropriate dosimeter.

SOMMAIRE

Numéro de Document: DREO TM 1999-109
Titre: Essais des dosimètres MGP DMC 2000S et NRC UDR-13A (U)
Auteurs: D. S. Haslip, T. Cousins, D. Estan, T. A. Jones, et B. Hoffarth
Centre de Recherche pour la Défense Ottawa

Étude Préliminaire: En tant qu'élément de sa mission continue fournir l'ingénierie et le support technique au projet G2199, DREO a testé le dosimètre électronique MGP DMC 2000S, le lecteur MGP LDM 2000, et le dosimètre NRC UDR-13A. Les essais ont inclus une caractérisation complète de leur réponse de rayonnement en fonction de la debit de dose et de l'énergie, des essais du lecteur de dosimètre de MGP, et des essais à bas et à hautes températures.

Résultats: Ces essais ont demonstré que les deux dosimètres sont appropriés au rôle d'un dosimètre électronique. Les deux ont des forces et des faiblesses contrastantes; le dosimètre MGP est petit et léger, avec une capacité de télécharger des données de mission à un lecteur, alors que le dosimètre NRC peut faire des rôles qui ne sont pas ceux du dosimètre électronique conventionnel, tel que la reconnaissance de rayonnement.

Les deux dosimètres ont aussi des problèmes. Leur réponses d'énergie ne sont pas constants. Ni l'un ni l'autre peut fonctionner pour longtemps aux températures en-dessous de –20°C. Finalement, si le dosimètre MGP est placé directement sur certaines parties du lecteur, il enregistre des niveaux très élevés de rayonnement.

Signification et des Futurs Plans: Ces resultats seront valeur à G2199 pour développer des besoins techniques du dosimètre électronique. CRDO va continueur à donner l'expertise nécessaire pour assurer qu'on achèterait le dosimètre le plus approprié.

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1 INTRODUCTION

The possibility of radiological exposure continues to be a source of concern to the Canadian Forces [1]. Such exposure need not result from a Cold War-style nuclear weapons exchange; the existence of nuclear reactors and the use of radioactive sources in industrial applications imply a variety of plausible hazardous scenarios as a result of accidents or deliberate and belligerent misuse [2].

Defence Services Procurement Project G2199 [3] is attempting to rectify the Canadian Forces' current inability to operate effectively in an area that may be radiologically contaminated. An important component of this project is personal dosimetry. Individual soldiers will likely be issued non-direct reading thermoluminescent dosimeters (TLDs). However, while these dosimeters provide a record of a soldier's exposure over a mission, they do not provide any real-time notification of exposure. For this reason, G2199 will also procure electronic dosimeters. These dosimeters will be issued to workgroups, rather than individuals, and may provide this group with the first indication of the presence of a radiological hazard.

As part of its Buy & Try program, G2199 has purchased dosimeters produced by NRC (the UDR-13A) and MGP (the DMC 2000S). The rudimentary performance characteristics of the UDR-13A were evaluated by DREO and described in a previous report [4]. Under tasking W28476KR00A, DREO was asked to perform a comprehensive evaluation of the DMC 2000S (along with the LDM 2000 reader), and compare the results of this evaluation with those for the UDR-13A (augmenting the previous testing where required). This document is the final report on this work.

2 THE DOSIMETERS

The NRC UDR-13A is a low-level dose rate version of the NRC UDR-13 portable radiac. Employing a high-range and a low-range Geiger-Muller tube, the UDR-13A provides dose and dose rate measurements from low levels to tactical levels of radiation. Its design is very rugged, and consequently it is both large and heavy for a dosimeter.

The MGP DMC 2000S is currently in use by the nuclear power industry. Variants of the meter are also in use by the French armed forces for tactical and low-level dosimetry, including monitoring sailors aboard nuclear-powered ships. The dosimeter is very small, employing a silicon diode for radiation detection. It communicates with the LDM 2000 dosimeter reader via a low-frequency (125 kHz), low-power magnetic coupling. This allows the dosimeter to be read without having to insert the dosimeter into the reader (as is required for the Siemens line of dosimeters), and indeed the soldier does not have to remove the dosimeter from his clothing in order to have it read.

3 TEST RESULTS – RADIATION DETECTION

3.1 Response to Cesium-137 and Cobalt-60 Fields

It is, of course, important to demonstrate that these dosimeters measure radiation dose accurately at both high and low doses and dose rates. This was performed at DREO by exposing the dosimeters to known doses from Cesium-137 (^{137}Cs) and Cobalt-60 (^{60}Co) sources. The gamma rays emitted by these sources are intermediate in energy (662 keV for ^{137}Cs, 1173 keV and 1333 keV for ^{60}Co), and should present no special difficulties for these dosimeters.

Figure 1 shows the response of these dosimeters to the ^{137}Cs field. The dosimeters were tested at dose rates from 10 μSv/h to 1 Sv/h, and given total doses between 1 μSv and 1 Sv. The delivered doses were calculated from the calibration of the source (in

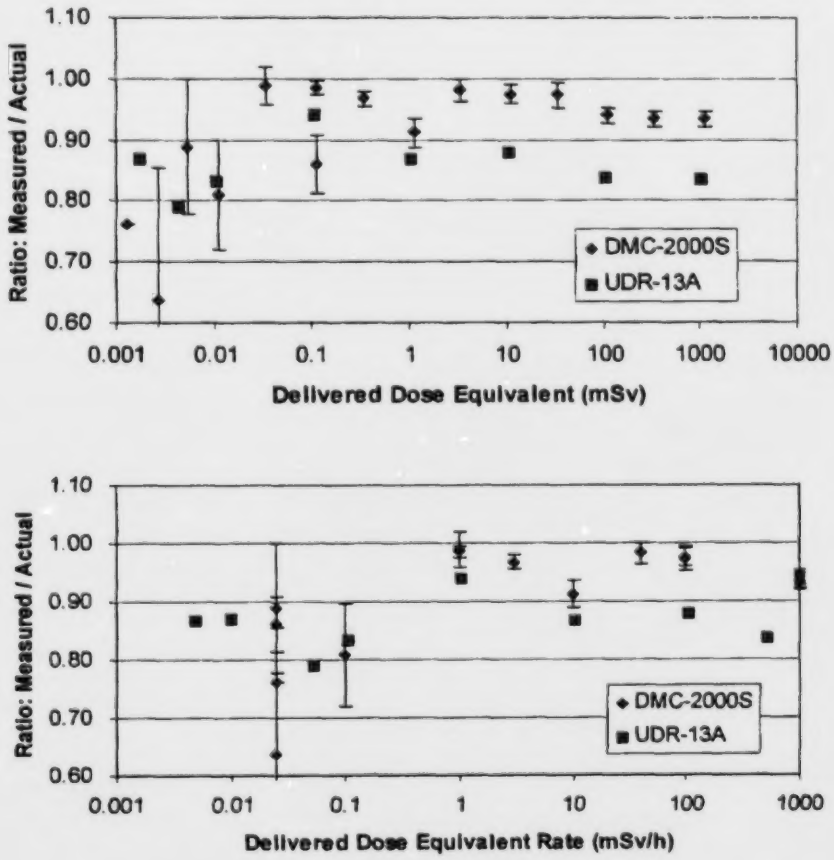

Figure 1: Ratio of measured dose to delivered dose as a function of delivered dose (upper panel) and dose rate (lower panel), from a ^{137}Cs source. The DMC 2000S appears to under-respond slightly at low dose rates.

Roentgens) and the ICRP conversion factor of 1.05 cSv/R. Three DMC 2000S dosimeters were tested. The figure shows the average response, with the error bars indicating the standard deviation of the three measurements.

The response of both brands of dosimeter is within twenty percent of the correct answer over most of their operating range. The primary exception to this rule is with the DMC 2000S at low doses and dose rates. However, the deviation here is relatively minor, and is primarily due to "round-off error". The DMC 2000S dosimeter measures doses to the nearest microSievert; thus, comparisons based on exposures of less than about 10 μSv are significantly affected (more than 10%) by the discretisation of the result.

The analogous plots for the ^{60}Co exposures are shown in Figure 2 (note that for Cobalt-60, the conversion factor is 1.02 cSv/R). The relative response of both dosimeters is different than for the ^{137}Cs. The DMC 2000S response is slightly smaller than it was for the cesium source. For improved accuracy, it might be worth changing its calibration constants, to introduce a slight over-response for ^{137}Cs, thus bringing the relative

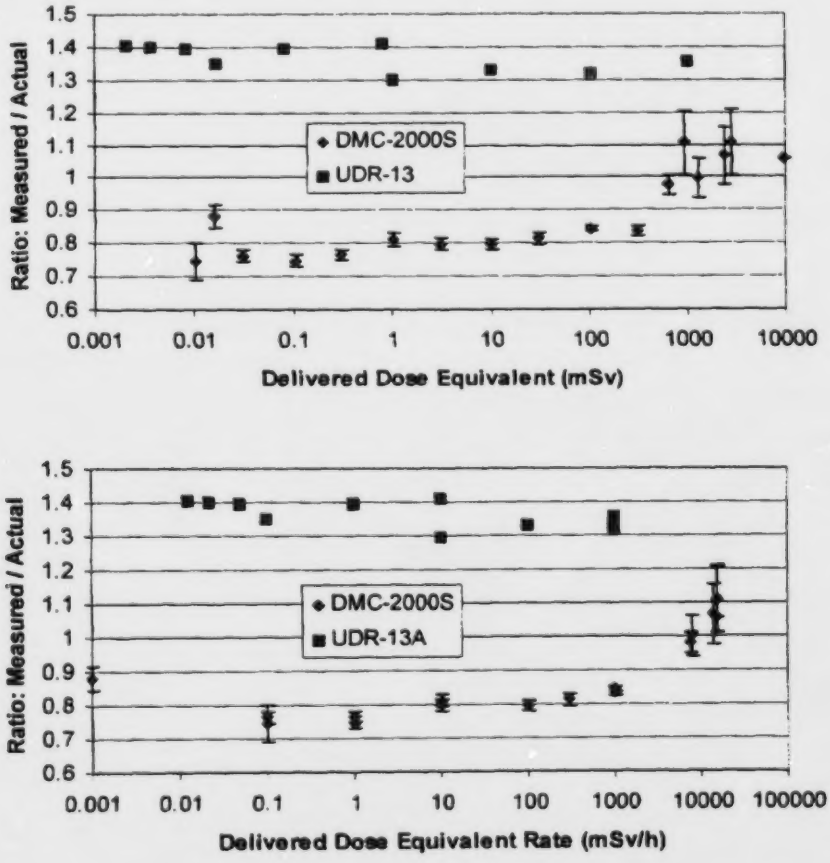

Figure 2: As for the previous figure, but for ^{60}Co. The DMC 2000S over-responds at very high dose rates.

response for the ^{60}Co source closer to unity. Of greater potential concern is the response of the UDR-13A. This dosimeter shows a signficant over-response at this energy, which would be more difficult to account for through changes in the calibration constants.

Finally, it should be noted that the relative response of the DMC 2000S rises sharply at very high dose rates. This presumably represents a failure of the electronics to account for very high rates (and dead times); however, problems at rates this high are essentially immaterial for the dosimeters' intended application.

3.2 Energy Dependence

Soldiers could encounter gamma-ray sources with a wide variety of energies. As seen in the previous section, however, the response of a dosimeter is not necessarily constant as a function of energy. In this section, the energy dependence of the dosimeters' response is examined.

DREO studied the energy dependence of these dosimeters in a number of ways. Table 1 summarises the energies studied in this work, and the ways that these energies were generated. In addition to using a number of encapsulated sources, the National Research Council X-ray machine was used to generate a series of ISO standard X-ray beams. Finally, the DREO Van de Graaff accelerator was used with various beam and target combinations to generate gamma rays from the target, and from neutron activation. Several of these sources are not monoenergetic, as indicated in the table. The mean energies given for these sources should only be regarded as approximate.

Table 1: Gamma-ray energies studied in this work, and how they were generated. Several of the sources were not monoenergetic; in these cases, the energy range and the mean energy are indicated.

Energy (keV)	Source
33	X-ray machine
48	X-ray machine
20 – 59 (mean 55)	Americium-241
65	X-ray machine
83	X-ray machine
100	X-ray machine
118	X-ray machine
164	X-ray machine
208	X-ray machine
279	Mercury-203
662	Cesium-137
1173, 1333 (mean 1253)	Cobalt-60
400 – 3500 (mean 1339)	Van de Graaff, 1 MeV $d + d \rightarrow {}^3He + 3.9$ MeV n
400 – 5200 (mean 3124)	Plutonium-Beryllium
400 – 8000 (mean 4628)	Van de Graaff, 1.5 MeV $p + F \rightarrow O + \gamma$
400 – 8000 (mean 5088)	Van de Graaff, 1.5 MeV $p + F \rightarrow O + \gamma + 0.4$ MeV n

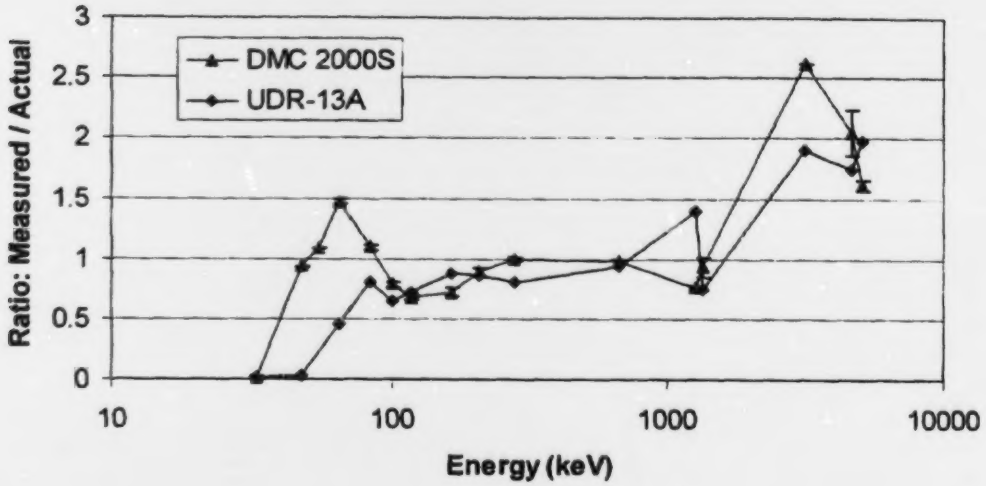

Figure 3: Relative response of the dosimeters as a function of gamma-ray energy. The UDR-13A shows a more or less monotonic dependence on energy, whereas the DMC 2000S exhibits a more exotic energy dependence.

Figure 3 shows the relative response of the dosimeters as a function of energy. The UDR-13A response rises more-or-less smoothly with energy, with a factor of two over-response at 5 MeV. At low energies, the response of the detector is compounded with absorption of the gamma rays in the thick case of the detector, so that relative response is below 50% at 65 keV, and falls off dramatically at smaller energies.

The response of the DMC 2000S is more irregular, with a pronounced bump below 100 keV. This response is *qualitatively* similar to that of the Siemens EPDs [5], and so may be a characteristic of silicon diode detectors. The important point to note is that the dosimeter retains virtually 100% response down to 50 keV.

There is another point of note here. The DMC 2000S dosimeters have been tested with the units set to millirem. However, the instruments do not attempt to account for the quality factor of the radiation measured; according to the dosimeters, 1 rem = 1 rad (1 Sievert = 1 Gray). This can be seen when the dosimeters are reset to use centiGrays. As it turns out, the quality factor of gamma radiation rises at low energies in much the same way as the DMC 2000S response. Thus, if we were to make the above comparison in centiGrays, the rise in response at low energies would be much more significant, rising as high as 2.5.

3.3 Dose Rate Fluctuations

As the concept of use for dosimeters in the Canadian Forces develops, questions may be raised regarding the extent to which a dosimeter could be used as a dose-rate meter. For instance, in lieu of waiting for a radiation survey meter to be brought forward, can a

dosimeter be used to do a preliminary survey of a radioactive source? Can a dosimeter be used to locate a radioactive source, such as a weapons fragment? Or, can a dosimeter be used to mark off the NATO hazard perimeter around a radioactive area?

The factor that mitigates the use of dosimeters in these roles is the sensitivity of the radiation detector. Dosimeter radiation detectors tend to be small, resulting in poor sensitivity and consequently they exhibit large fluctuations in the measured dose rate in a low but constant field. This makes it difficult to use the dosimeter to find a source, or to mark off a perimeter, since the dose rate is constantly changing.

Figure 4 shows the relative response of the two dosimeters to ^{137}Cs and ^{60}Co sources. The error bars on this figure show the magnitude of the fluctuations in the measured dose rate on the dosimeters, over a period of one to two minutes. It is apparent that the UDR-13, with its sizeable detectors, exhibits only very small fluctuations down to 0.1 mSv/h. The DMC 2000S, however, exhibits sizeable fluctuations at low dose rates. At 0.1 mSv/h, the reported dose rate swings as much as 30% in both directions. It should also be noted that while using the Americium-241 source, 100% fluctuations were observed with a dose rate of 30 μSv/h. Clearly, it is not reasonable to expect personnel to perform survey or reconnaissance tasks with these dosimeters in low-level radiation fields.

It should be noted that the fluctuations in count rates can be reduced by increasing the averaging time of the dosimeter. While MGP could potentially be approached about changing this averaging time, recent experience with use of the ADM-300 at CFNBCS has shown that long integration times can result in another set of problems.

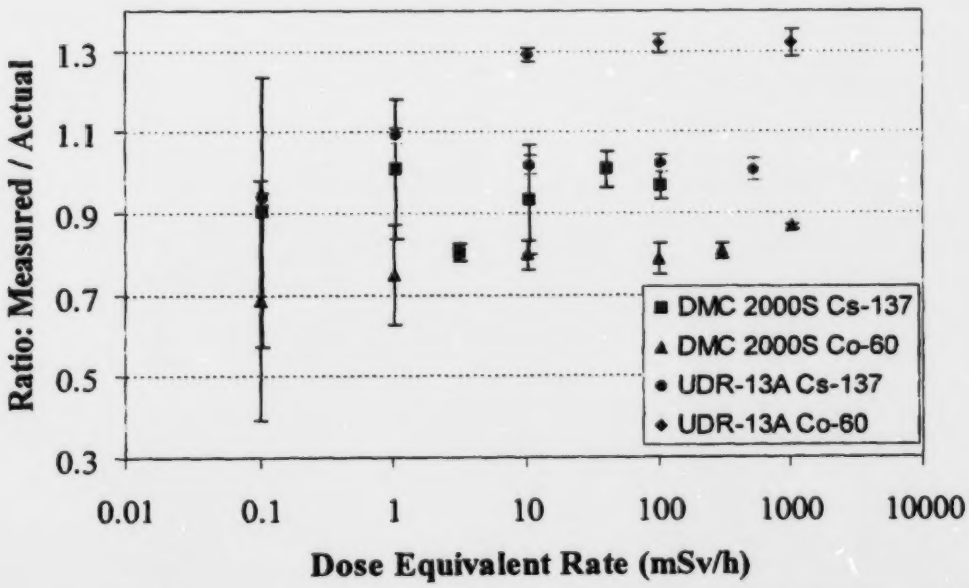

Figure 4: Fluctuations in the reported dose rate from the dosimeters, for ^{137}Cs and ^{60}Co sources. The error bars indicate the range of dose rates measured over a period of one to two minutes.

3.4 Sensitivity to Other Radiation

The dosimeters were tested for sensitivity to alpha and beta radiation with a variety of check and area sources. The dosimeters were laid on a Thorium-232 alpha area source, with an activity of 0.0522 Bq/cm^2 for 17 hours, and counted only background rates. Beta check sources of Strontium-90 and Chlorine-36 were laid on the dosimeters, over the detector position, for 19 hours. Again, only background was counted, despite beta dose rates in the neighbourhood of 0.04-0.5 mSv/h. We conclude on the basis of these tests that the dosimeters are insensitive to alpha and beta radiation, as advertised. The upcoming tests in Bourges, France will permit a closer study of the beta sensitivity.

Neutron sensitivity was checked in conjunction with the high-energy gamma sensitivity, with the Plutonium-Beryllium source and the Van de Graaff accelerator. A run at the Van de Graaff with negligible neutron output demonstrated the dosimeters response to high-energy gamma rays. Subsequent runs with combinations of gamma rays and neutrons confirmed the over-response to high-energy gamma rays, and established that the meters have negligible response to neutrons. These tests were quite stringent; in some of the runs, the dosimeters were exposed to milliSieverts of neutron dose, and registered nothing more than what would be expected for the gamma exposure. Thus, it is concluded that these meters are not sensitive to neutrons, except through their production of gamma rays through neutron activation.

4 TEST RESULTS – DOSIMETER / READER COMMUNICATION

Three aspects of the remote communication between the DMC 2000S dosimeters and their reader were tested. These are (a) the time it takes to pass through a check-point and be read, (b) the range and isotropy of the communication system, and (c) how the range of the system is affected by shielding.

The time for data exchange was determined by bringing a collection of people through a checkpoint, reading each person's dosimeter in turn. This simple test established that the time for dosimeter reading is between seven and eight seconds, in agreement with the results of D. Turbide [6].

The range and isotropy of the communication system were established by approaching the reader while wearing the dosimeter, from a variety of angles around the dosimeter. When the reader detected the dosimeter, the dosimeter would beep, and the subject would stop moving, allowing the reader and dosimeter to communicate. If the communication was error-free, then this was recorded as a measurement of the range. It should be noted that the communication often failed, since it was being carried out at the limit of its range. Measurements were made with the reader mounted on a table, and with it mounted on a wall. Measurements were also made with the dosimeter worn exposed, worn under a flak jacket, and with the wearer approaching the reader backwards (using his own body as shielding). Six range measurements were made at each angle for each shielding condition and reader mount.

The results of these tests are shown in the radar plots in Figure 5. The ranges are

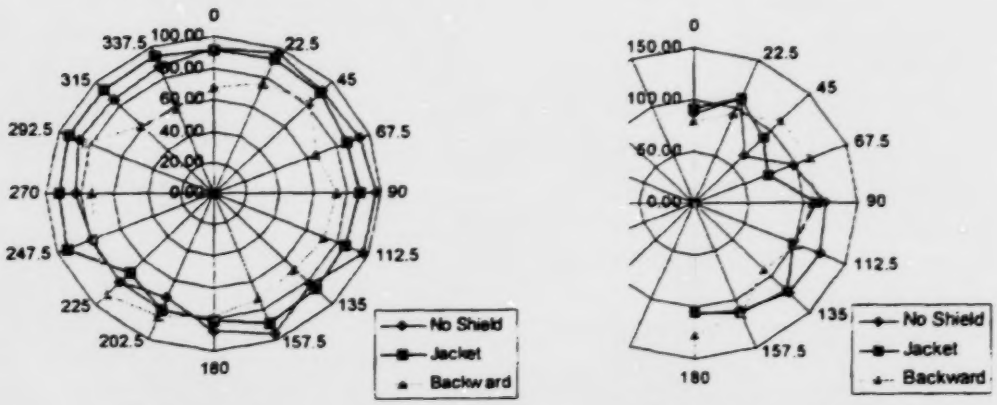

Table Mount Wall Mount

Figure 5: Range of dosimeter-reader communication for table- and wall-mounted readers, using no shielding, a flak jacket, or a human body for shielding. Ranges are indicated by the distance from the centre of the radar plot. The range axis is labelled in centimetres.

virtually isotropic, with no preferred direction of approach. None of the shielding configurations presented serious communication difficulties, although there is some evidence that the presence of the human shielding (backward approach) decreased the range as much as ten centimetres, on average. It should also be noted that the range is increased by approximately twenty centimetres through the use of a wall mount. The wall mount is, in fact, the method of use prescribed in the user manual, although perhaps not the way it would be used in-theatre. It should also be noted that, while the effect of metal shielding was not rigorously examined, it was observed that metal is quite effective at blocking the communication. This is mentioned in the reader manual; the reader is not supposed to be installed on a metal surface, with the warning that such a mount will significantly decrease the range of the reader.

Another peculiarity of the dosimeter-reader system was observed during testing. When the dosimeter is brought within a few centimetres of certain locations on the reader, it responds as if exposed to very high levels of radiation. That is, the dose rate display indicates tens or hundreds of microSieverts per second, the total dose display accumulates accordingly, and alarms can be set off. This is presumably a bug related to some form of interference with the dosimeter electronics. If this bug persists into a version of the meter used in operations, extreme care should be exercised with regard to placing dosimeters near the reader. There are few dosimeter problems more frightening than a dosimeter that records high radiation levels when it is not exposed.

5 TEST RESULTS – LOW TEMPERATURE PERFORMANCE

The DMC 2000S dosimeters and the UDR-13A were tested by DREO personnel at the Quality Engineering Test Establishment (QETE) in one of their room-size temperature chambers. The dosimeters were exposed to radiation from a small (few milliCurie) ^{60}Co source at 48°C, 40°C, 21°C, -1°C, -10°C, -21°C, -29°C, and -39°C. At each temperature, the dosimeters were left for an hour or two to equilibrate, and then exposed to approximately 0.1 mSv from the Cobalt source. Following the exposure, the user would attempt to read the total dose on the display, toggle the dosimeter into dose rate mode to test the operation of the button, and try to communicate with the reader (with both pieces of equipment outside the environmental chamber). The reader was never taken into the chamber, and so remained at room temperature (20°C) throughout the testing.

No irregularities were observed in the tests between 48°C and -10°C. At all of these temperatures, the units accurately measured the radiation exposure, and suffered no observable performance degradation. At -21°C, performance remained acceptable, but the dosimeters were slow to change modes when the user pressed the buttons.

The dosimeters were then brought to -39°C. At this temperature, all of the dosimeters failed to operate. LCD displays failed to function, mitigating the testing of display toggling. In addition, the dosimeters were unable to communicate with the reader. This may be related to the condition of the dosimeter batteries. At these temperatures, the DMC 2000S battery failure warning light came on and stayed on until the dosimeters were warmed up.

The dosimeters were then warmed up to -29°C. Even at these temperatures, the UDR-13A failed to operate, with the LCD completely blank. The DMC 2000S dosimeters regained functioning LCDs after up to two hours of waiting; the dosimeters were unable to toggle modes, however, and the battery warning lights stayed lit. Reader communication was sporadic. It is not certain whether all of these problems would have been encountered if the dosimeters had not already been at an even lower temperature. However, time constraints prevented further tests.

In conclusion, all of the dosimeters appear to function well down to -20°C. At temperatures of -30°C and below, significant degradation in dosimeter function is likely. However, if the dosimeters are worn inside a winter coat, their temperature could likely be kept above -20°C without too much trouble.

6 CONCLUSIONS AND RECOMMENDATIONS

The DMC 2000S and the UDR-13A have been exposed to some of the most extensive testing of radiation equipment ever undertaken by DND. The results of some of this testing can be seen in Table 2 below. The table compares the performance of the two dosimeters against the specifications of a tactical dosimeter given in the addendum to NATO Triptych D/104 [7], which outlines the requirements of low-level radiation equipment.

Both dosimeters measure up in a similar way to the D/104 specifications. The dose limits are easily satisfied. Both units have alarms. Neither unit, however, satisfies the requirement that energy response vary by no more than 20% referenced to a chosen calibration source (where ^{137}Cs has been taken to be this source). If the accuracy restriction was relaxed to 30%, the DMC 2000S would satisfy the essential requirement; the UDR-13A, however, has a somewhat more pronounced energy dependence in the 80 keV – 1.5 MeV range. Such issues must be addressed as the Technical Statement of Requirements is developed for the Electronic Dosimeter, and indeed this is already well under way.

Among the environmental requirements, there are somewhat more unanswered issues. Pressure, humidity, vibration, and NBC survivability issues have not been addressed in this testing. The temperature testing that was completed showed that neither dosimeter satisfies the low-temperature requirement of D/104. This shortcoming will have to be addressed by wearing the dosimeter under winter garments.

Table 2: Dosimeter performance as measured against the D/104 specifications.

Parameter	D/104 Specification	DMC 2000S	UDR-13A
Dose – Lower limit	50 μGy	✔	✔
Dose – Upper limit (essential)	0.1 Gy	✔	✔
Dose – Upper limit (desirable)	1 Gy	✔	✔
Alarms	Desirable	✔	✔
Energy – Lower limit (essential)	80 keV	×	×
Energy – Lower limit (desirable)	50 keV	×	×
Energy – Upper limit (essential)	1.5 MeV	×	×
Energy – Upper limit (desirable)	3 MeV	×	×
Pressure – Lower limit	15000 m	?	?
Temperature – Lower limit	-30°C	×	×
Temperature – Upper limit	50°C	✔	✔
Humidity	100%	?	?
Vibration and Shock	Various	?	?
NBC Survivability	AEP-4, AEP-7	?	?

This testing has also addressed in some detail the dose-rate response of the dosimeters. It has been shown that the DMC 2000S is not suitable for any radiation reconnaissance or survey in LLR fields; indeed, it cannot register dose rates below 10 μSv/h (3 times the NATO turnback rate). Doctrinal decisions about the use of electronic dosimeters in the field must be established, since these have major ramifications on the kind of dosimetry that G2199 should procure. Of course, in light of the cold-temperature results, it should be noted that the UDR-13A is not suitable for reconnaissance below –20°C.

The wireless communication between the DMC 2000S and the LDM 2000 reader is an effective method of communication. The unit has a maximum range of approximately one metre, although use at shorter distances goes a long way towards eliminating communication errors. The computer software required to run the reader is obviously still under development; G2199 should be aware of this. In addition, the bug in the dosimeter that leads to false measurement of high levels of radiation when the dosimeter is placed too close to the reader is a source of concern. If this bug were to manifest itself during operations, it could cause considerable panic.

7 REFERENCES

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